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13. ABSTRACT *(Maximum 200 words)*
Purpose: This study examined the effects of hypohydration and moderate hyperthermia (core temperature elevation) on anaerobic exercise performance in a temperate environment. Methods: Eight active males completed two passive heat exposure trials (180-min, 45°C, 50%rh) with (EUH) and without (HYP) fluid replacement. A single 15-s Wingate Anaerobic Test (WAnT) was used to assess anaerobic performance (peak power, mean power, and fatigue index) before (-180-min) and again at three time points after passive heat exposure to include immediately after (0-min), 30-min and 60-min post in a temperate environment (22°C). Rectal temperature (Tc) was measured throughout the experiment. Results: HYP reduced body mass (2.7 ± 0.7%) ($P<0.05$) but had no effect on any WAnT performance measure. Passive heat exposure elicited moderate hyperthermia in both trials (0.6°C, EUH vs. 1.0°C, HYP) and returned to baseline within 30-60-min following similar decay curves. HYP Tc remained higher (0.4°C) than EUH throughout testing ($P<0.05$), but moderate hyperthermia itself produced no independent effect on anaerobic exercise performance in either trial. Conclusions: This study demonstrates that neither moderate HYP, nor the moderate hyperthermia accompanying HYP by passive heat exposure, affects anaerobic exercise performance in a temperate environment.

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No Effect of Moderate Hypohydration or Hyperthermia on Anaerobic Exercise Performance

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ABSTRACT

CHEUVRONT S. N., R. CARTER, E. M. HAYMES, and M. N. SAWKA. No Effect of Moderate Hypohydration or Hyperthermia on Anaerobic Exercise Performance. *Med. Sci. Sports Exerc.*, Vol. 38, No. 6, pp. 1093–1097, 2006. **Purpose:** This study examined the effects of hypohydration and moderate hyperthermia (core temperature elevation) on anaerobic exercise performance in a temperate environment. **Methods:** Eight active males completed two passive heat exposure trials (180 min, 45°C, 50% rh) with (EUH) and without (HYP) fluid replacement. A single 15-s Wingate anaerobic test (WAnT) was used to assess anaerobic performance (peak power, mean power, and fatigue index) before (−180 min) and again at three time points after passive heat exposure to include immediately (0 min), 30 min, and 60 min after in a temperate environment (22°C). Rectal temperature (T_c) was measured throughout the experiment. **Results:** HYP reduced body mass (2.7 ± 0.7%) ($P < 0.05$) but had no effect on any WAnT performance measure. Passive heat exposure elicited moderate hyperthermia in both trials (EUH: 0.6°C; HYP: 1.0°C) and returned to baseline within 30–60 min following similar decay curves. HYP T_c remained higher (0.4°C) than EUH throughout testing ($P < 0.05$), but moderate hyperthermia itself produced no independent effect on anaerobic exercise performance in either trial. **Conclusions:** This study demonstrates that neither moderate HYP nor the moderate hyperthermia accompanying HYP by passive heat exposure affect anaerobic exercise performance in a temperate environment. **Key Words:** DEHYDRATION, POWER, WINGATE, CYCLE ERGOMETRY, RECOVERY

Hypohydration (a body water deficit) is a common consequence of sport and occupational work. It may be used intentionally by athletes in weight-class sports (e.g., wrestling), or it may result from heavy sweating when occupational tasks require exposure to great heat (e.g., firefighting). In many sports and occupations where hypohydration is likely, high levels of anaerobic power are frequently a prerequisite for performance success (14,21). However, whether hypohydration alters anaerobic exercise performance remains an important question with no definitive answer (13,15,16,18,20,23,27,28,30,31).

It is well established that hypohydration reduces aerobic exercise performance (10,24). One explanation for equivocal research findings involving hypohydration and anaerobic exercise performance may be the use of dissimilar study methodologies. The effect of hypohydration on anaerobic exercise performance is often measured using a single-bout Wingate or similar supramaximal cycle ergometer test (13,15,20,23,30,31), but body mass–dependent tests like the vertical jump (16,27) and track (28) or treadmill sprinting (18) have also been used. The latter are difficult to interpret, however, because of inherent changes in the force-to-mass relationship that result from hypohydration. It is also known that similar levels of hypohydration attained using passive heat exposure, exercise, or diuretic administration can produce different effects on exercise performance (8,23). This adds to study interpretation difficulty because diuretics (23,28), passive heat exposure (20,23), exercise (16,23,31), concurrent exercise-heat exposure (13), or a variety of methods used simultaneously (14,18) have been employed to produce hypohydration. The presence of hyperthermia that accompanies hypohydration also holds the potential to independently influence anaerobic exercise performance positively (2,4) or negatively (12,23), but core temperature is infrequently reported (13,23,31), and the time lapse between heating and testing also varies considerably among reports.

This study examined the effects of hypohydration and moderate hyperthermia on anaerobic exercise performance in a temperate environment. Passive heat exposure (sauna) was chosen as a simple means of losing body water that avoids the potentially confounding effects of exertion (23) or drug administration (7). The effect of hyperthermia was quantified by its induction and decay using serial core temperature (T_c) measurements. Anaerobic exercise performance was evaluated using a single-bout Wingate anaerobic test (WAnT), which requires large anaerobic energy demands (6,19) and affords study of hypohydration performance effects independent of force-to-mass relationships. Our hypotheses were that 1) hypohydration would not alter WAnT performance but that 2) moderate hyperthermia would degrade performance.

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METHODS

Subjects. Eight healthy and physically active male subjects volunteered to participate in this study. One week before experimental testing, anthropometric and fitness measurements were made. Peak aerobic power ($\dot{V}O_{2peak}$) was measured using an incremental cycle ergometer protocol with continuous gas exchange measurements (Parvo Medics, Inc., Sandy, UT), and body fat percentage was determined from skinfolds using standard formulas. Subject characteristics were (mean ± SD (range)): age 28 ± 5 yr (19–33), body mass 77.5 ± 10.8 kg (59.8–97.3), height 181 ± 5 cm (173–188), body fat 11.3 ± 4.4% (4.9–15.2), $\dot{V}O_{2peak}$ 52 ± 6 mL·kg^{-1}·min^{-1} (47–63). Volunteers were blinded to the study hypothesis. The appropriate institutional review boards approved this study. Subjects were provided informational briefings and gave voluntary and informed written consent to participate.

Preliminary procedures. One week before experimentation, three performance familiarization sessions were completed separated by 30 min each to mirror the experimental testing scenario to follow (17). The WAnT was chosen as a repeatable, dynamic exercise performance task with application to sports requiring large anaerobic energy demands (19). A single WAnT bout with ample recovery periods was chosen for its similarity to existing work (20) and to minimize the aerobic contribution to performance (6), which is degraded by exercise-induced hypohydration when supramaximal exercise bouts are intermittent (22). The classic 30-s test was further modified to 15 s to improve suitability for repeat testing (17) without compromising test reliability (19,29). Individual WAnT resistance was set at 0.075 kp·kg^{-1} (19). Scores for peak power output (PPO) were given to each subject for feedback and motivation to improve with each session. A plateau in performance (no statistical difference) was observed for sessions 2 and 3, and a coefficient of variation was calculated (3.6%) from the mean and SD of these sessions to estimate sample size. The reliability observed was consistent with the published literature (29). All testing was performed on an electrically braked cycle ergometer interfaced to a PC with WAnT-enabling software allowing data sampling rates of 5× s^{-1} for all performance parameters (Lode Excalibur Sport, Lode, Groningen, The Netherlands).

Experimental procedures. Two experimental trials (euhydration, EUH and hypohydration, HYP) were completed in crossover fashion separated by 7–10 d. Subjects were instructed to limit physical activity 48 h before each trial and to drink at least 200 mL of water the night before and the morning of testing. Food intake was restricted 4 h before scheduled arrival at the laboratory. Upon arrival, a urine sample was voided, and hydration status was determined by urine specific gravity analysis (Leica Optical products Division, Buffalo, NY) employing < 1.02 g·mL^{-1} as a euhydration index (1). Seminude (shorts only) body mass was measured on a calibrated digital scale (± 100 g, SR Instruments, Inc., Tonawanda, NY). Instrumentation included self-insertion of a rectal thermistor (YSI, Yellow Springs, OH) 10 cm beyond the anal sphincter for the measurement of T_c by precision thermometer (YSI, Yellow Springs, OH). The same pre-experimental procedures were followed on the morning of both trials, and all experiments were conducted at the same time of day.

Each trial consisted of four WAnT bouts performed in a temperate laboratory environment (22°C, 65% rh). The first bout (WAnT-1) occurred before the start of passive heat exposure (−180 min). Each WAnT began with 60 s of unloaded cycling at a cadence of 60 rpm. A 5-s countdown followed, after which 15 s of supramaximal cycling ensued without encouragement and with the performance outcome double blinded. Performance indices included peak power output (PPO), mean power output (MPO), and fatigue index (FI). PPO and MPO performances were evaluated in both absolute (W) and relative (W·kg^{-1}) terms. The FI is the rate of fatigue or degree of power dropoff expressed as a percentage of PPO according to the formula: FI = [(PPO − minimum PO)/PPO] × 100 (19).

Immediately after WAnT-1, subjects sat for 180 min in a hot room (45°C, 50% rh) and were interrupted at 15-min intervals for weighing. No fluid was provided during the HYP trial, but water was provided in EUH to prevent hypohydration (as determined by body weight changes). After completing the 180-min heat exposure, body mass was again recorded one final time. WAnT-2 was performed within 5 min (0 min), WAnT-3 at 30 min, and WAnT-4 at 60 min after heat exposure using the same procedures and in the same environment as WAnT-1 (−180 min). In the HYP trial, resistance (0.075 kp·kg^{-1}) (19) was set according to prehypohydration body mass (20) to test for hypohydration performance effects independent of force-to-mass relationships. Relative power was always calculated using actual body mass to assess the potential for hypohydration to affect power production per unit of body mass. T_c was measured throughout testing.

Statistical analysis. Data were analyzed for normality of distribution and equality of variances. Treatment effects were analyzed by two-way ANOVA (trial × time) for repeated measurements or paired *t*-test (trial), depending on the variable of interest. Where the assumption of sphericity was violated, results were corrected using Greenhouse–Geisser or Huynh–Feldt values as recommended by Atkinson (3). Simple correlation coefficients were used to describe associations among variables of interest. Nonlinear regression was used to compare T_c decay curves. Tukey's HSD procedure was used to identify pairwise differences among means following significant main and/or interaction effects. A power analysis selecting conventional α (0.05) and β (0.20) values showed eight subjects would be sufficient to detect a minimum effect equal to twice the coefficient of variation observed during WAnT practice sessions (3.6%) and twice the anticipated standard deviation (0.25°C) for T_c, which was estimated using a comprehensive reference for daily T_c variation (11). The effect magnitude was selected based on the likelihood that the experimental procedures would produce some unique and additive response variability (17), whereas smaller differences were considered of marginal importance. Graphical data are presented with unidirectional error bars and slightly juxtaposed for presentation clarity. All data are presented as means ± SD.

RESULTS

Hydration. All eight subjects produced urine samples with specific gravity < 1.020 $g \cdot mL^{-1}$ prior to the start of both trials. The mean urine specific gravity between trials was also similar (P = 0.78). Passive heat exposure for trial HYP resulted in a 2.0 ± 0.5 kg loss of body mass (2.7 ± 0.7%, range = 1.7–3.6%), which was significantly different from baseline and trial EUH (+ 0.1 ± 0.2 kg) (P < 0.001).

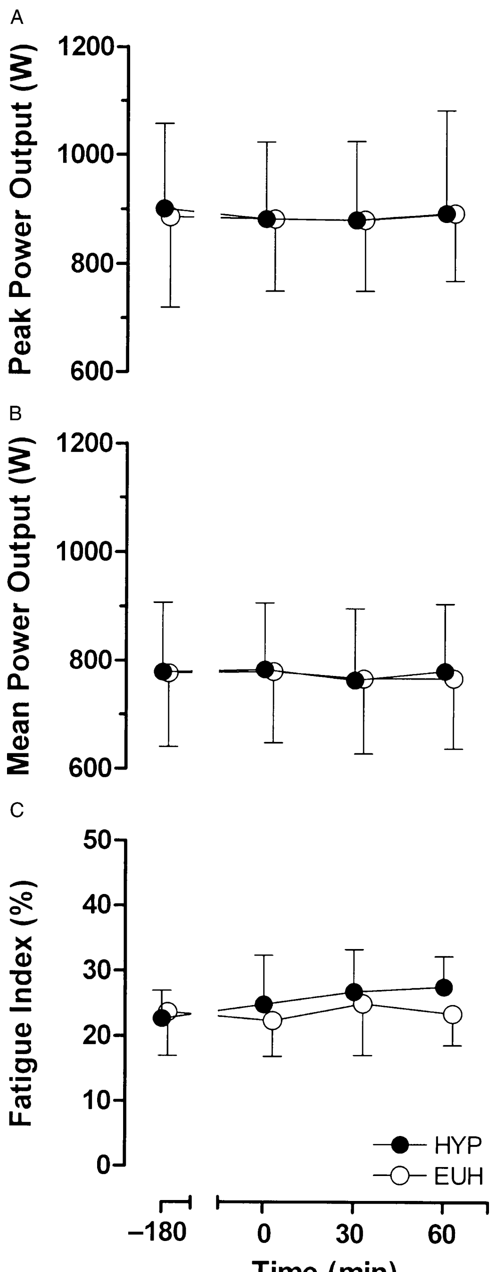

FIGURE 1—Influence of trial and time on WAnT performance parameters of PPO (A), MPO (B), and FI (C). Values are means ± SD.

Performance. No effect of T_c (time, P = 0.65) or hydration (trial, P = 0.67) was observed for the primary WAnT performance outcome measure in this experiment (PPO), nor were any interactions observed (Fig. 1A). Correlation analyses also showed no association between either hypohydration level (percent body mass) or change in T_c when examined against PPO (r^2 = 0.00 in both cases). Absolute PPO collapsed across time (0–60 min) were 888 ± 123 and 884 ± 153 W for EUH and HYP, respectively. Relative PPO were 11.4 ± 1.0 and 11.7 ± 1.3 $W \cdot kg^{-1}$ for EUH and HYP, respectively. Similarly, no differences were observed for MPO (Fig. 1B) whether expressed in absolute (EUH: 775 ± 121 W; HYP: 770 ± 127 W) or relative (EUH: 9.9 ± 1.0 $W \cdot kg^{-1}$; HYP: 10.1 ± 1.0 $W \cdot kg^{-1}$) terms. Differences for FI were small both between and within trials (Fig. 1C). There was no effect of trial order, and WAnT reliability (calculated from time points 0, 30, and 60) remained similar to training values (CV = 2–4%) in both trials.

Core body temperature. Figure 2 illustrates the T_c response to and decay following 180 min of passive heat exposure. T_c at 0 min was significantly higher than baseline in both trials, but T_c was also higher in HYP when compared with EUH at the same time point. Thereafter, T_c was not different from baseline in EUH but remained higher than baseline for HYP at 30 min. The slopes of the T_c decay curves (0–60 min) were similar for both trials, but HYP T_c remained higher (~0.4°C) than EUH throughout the entire 60-min period (Fig. 2) (P = 0.02–0.04).

DISCUSSION

This study examined the potential effects of hypohydration and moderate hyperthermia by passive heat exposure on anaerobic exercise performance in a temperate environment. The principal findings of this study were that neither

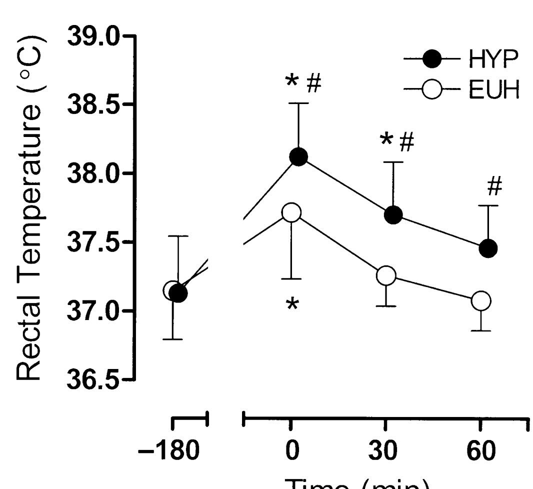

FIGURE 2—Influence of trial and time on T_c. *P < 0.05 from baseline (−180 min). # P < 0.05 between trials. Values are means ± SD.

moderate hypohydration nor the moderate hyperthermia that accompanies passive heat exposure affect anaerobic exercise performance.

The hypohydration level employed (> 2% body weight loss) is known to impair aerobic exercise performance in temperate environments (10). Core body temperature was increased to more than 38°C, which approximates the recommended limits for sustained occupational work (26) but is well below what is often associated with heat exhaustion or fatigue (9). Testing was conducted in a temperate laboratory to minimize potential independent environmental heat effects (4). The impact of moderate hyperthermia on performance was quantified by measuring core temperature changes (induction and decay) over time in conjunction with serial WAnT before and after passive heating. A 15-s WAnT was chosen as the anaerobic exercise performance measure because of its reliability (29) and logical extrapolation to tasks requiring high anaerobic energy demands (6,19).

Hypohydration by 2.7% of body mass did not alter anaerobic exercise performance as measured using a 15-s WAnT. This finding is in agreement with that reported by Jacobs (20), who employed a very similar hypohydration and test performance methodology while using three levels of hypohydration (2, 4, and 5%) but with 30 min of recovery from passive heat exposure (56°C, ~120 min) permitted before testing at each level. Core body temperature was not reported (20), but our data (Fig. 2) suggest that heat strain should have been minimal. Others have demonstrated hypohydration-mediated reductions in anaerobic exercise performance using WAnT or similar tests (13,23,30,31) but with possible confounding factors. Webster et al. (30) reported a substantial decline in WAnT PPO after hypohydration by exercise in a rubber suit the night before testing, but the absence of a control trial employing the same methods without hypohydration makes firm conclusions tenuous. The other experiments measured the impact of hypohydration on anaerobic exercise performance intermittently during (13) or following (23,31) vigorous exercise accompanied by moderate (31) or large (13,23) increases in body temperature. The difference in T_c between HYP and EUH in this study was small, neither differed from baseline after 60 min (Fig. 2), and at no time was performance influenced by $T_{c,}$, hydration state, or their combination (Fig. 1). It is therefore likely that one or more factors independent of hydration status (e.g., prior exercise, severe hyperthermia) could have influenced the anaerobic performance outcomes in other studies.

Moderate hyperthermia alone or in combination with HYP did not affect WAnT performance in a temperate environment. Core temperature was highest (~38°C) immediately following passive heat exposure (Fig. 2), but this magnitude of hyperthermia was less severe than that elicited by the combination of exercise hypohydration in studies where anaerobic exercise performance was impaired (13,23). The effects of heat itself on PPO are highly contingent. There is evidence that local muscle heating by exercise (2,5) or radio diathermy (2) improves PPO. In contrast, mild whole-body heating produces mixed effects (2,4), whereas severe elevations in both muscle and core temperatures (~39.5°C) using exercise or hot water immersion impair PPO (12). The passive heat exposure used in this study is similar to that used by others (20,25), and similar core temperatures have been reported (25) following hotter intermittent sauna exposures (80°C) of shorter duration (120 min). Although muscle temperatures were not measured in this study, it appears that changes in muscle or core body temperatures larger than those achieved with sauna-like hypohydration may be necessary to elicit performance altering effects for anaerobic exercise.

In summary, this study demonstrates that neither moderate HYP nor the moderate hyperthermia accompanying passive heat exposure affect anaerobic exercise performance in a temperate environment. These findings are limited in scope to the methodology described but suggest that factors coexistent with hypohydration in other studies may play a role in influencing anaerobic exercise performance outcomes.

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